

Hydrodynamic properties of rotary-disc extractor. I. Distribution of the sizes of drops and their residence times

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Received 10 May 1976

Accepted for publication 23 September 1976

The distribution of the sizes of drops in a rotary-disc countercurrent extraction column was experimentally established for the system water (continuous phase)—toluene (dispersed phase) by photographing the dispersion during interfacial substance transfer (acetone). The results obtained were correlated with some published expressions for the drop size distribution and a relationship between the parameters of convenient distribution and the quantities characterizing the hydrodynamic regime in equipment was derived. Moreover, the validity of some relationships for the calculation of mean diameters of drops was verified.

Экспериментально определялось распределение размеров капель в роторно-дисковой противоточной экстракционной колонне для системы вода (сплошная фаза)—толуол (дисперсная фаза) при условиях межфазного перехода вещества (ацетон) при помощи фотографирования дисперсии. Полученные данные сравнивались с некоторыми опубликованными соотношениями для распределения размеров капель и был найден вид зависимостей параметров, подходящего разделения, от величин, характеризующих гидродинамический режим в колонне. Кроме этого сделана проверка некоторых соотношений для расчета средних диаметров капель.

Rotary-disc extractor with mechanical stirring designed by *Reman* [1] as well as its construction modifications is increasingly applied in chemical and technological practice as an efficient separation equipment. This circumstance makes increased demands on the design of extractors which is due to the properties of two-phase flow in the apparatus. The real hydrodynamic regime in column determines the dispersion character of dispersed phase which for a change so influences the interfacial transfer of substance that the concentration of transferred substance approaches to the equilibrium value earlier in smaller drops, which have a longer residence time in the apparatus and a larger specific surface, than in larger drops. In

addition, the motion of drops itself affects the flow character of continuous phase.

The hold-up of dispersed phase Z defined as the ratio of the volume of dispersed phase to the volume of equipment is an important hydrodynamic characteristics of two-phase flow

$$Z = \frac{V_d}{V} \quad (1)$$

Up to now, no relationship has been derived which describes the drop size distribution in the equipment on the basis of a theoretical analysis of the problem in connection with physical properties of both phases and stirring conditions. The distribution gives either the relationship between the relative number of drops and their size which is represented by the distribution function $F(d)$ and frequency function $f(d)$ or the relationship between the relative volume of drops and their size which is represented by the distribution function $V(d)$ and frequency function $v(d)$. The expressions used in this field are either a generalization of experimental results or are founded on simplified ideas of the properties of turbulent flow [2—6].

Every distribution of probability may be characterized by initial and central moments. For the distribution of the sizes of drops the quantity d_{pq} defined by the following expression [7] is frequently used

$$d_{pq} = \frac{\int_0^{\infty} d^p f(d) dd}{\int_0^{\infty} d^q f(d) dd} = \frac{\sum_{d_{\min}}^{d_{\max}} n_i d_i^p}{\sum_{d_{\min}}^{d_{\max}} n_i d_i^q} \quad (2)$$

This quantity is denoted as mean diameter of drop of the p — q order and its use is based on the physical essence of the investigated process. By using the Kolmogorov theory of local isotropic turbulence and the Levich theory of drop splitting in turbulent flow several authors derived expressions [8—12] for the dependence of mean diameters of drops or maximum stable diameters of drops d_m on mixing conditions. The validity of some of these relationships is verified in this paper. It may be proved that

$$v(d) = \frac{d^3}{d_{30}} f(d) \quad (3)$$

$$V(d) = \frac{d^3}{d_{30}} F(d) \quad (4)$$

The experimental size distribution was compared with the distribution suggested by Přerovská [2]

$$v\left(\frac{d}{d_m}\right) = \frac{1}{6\beta^4} \left(\frac{d}{d_m}\right)^3 \exp\left[-\frac{d}{\beta d_m}\right] \quad (5)$$

where β and d_m are the parameters of distribution. Furthermore, it was compared with the Schwarz distribution [3]

$$f(d) = \frac{B}{d^5} \exp\left[-\frac{\bar{a}}{d}\right] \quad (6)$$

where \bar{a} and d_m are parameters while the quantity B is defined in terms of them

$$B = \frac{\bar{a}^4 \exp\left[\frac{\bar{a}}{d_m}\right]}{6\left(1 + \frac{\bar{a}}{d_m} + \frac{\bar{a}^2}{2d_m^2} + \frac{\bar{a}^3}{6d_m^3}\right)} \quad (7)$$

The selection of these expressions was made because of their relative simplicity. As for the expressions recommended for the calculation of mean diameter, we verified the *Pebalk* equation [11]

$$d_{32} = \frac{0.238 \sigma^{0.6}}{\rho_c^{0.2} E'^{0.4}} \quad (8)$$

where E' represents the input referred to a unit of stirred substance in the system and can be determined from the criterial relation put forward by *Mišek* [14] in the form

$$\frac{P_d}{N^3 D_r^5 \rho_c} = 0.069 \left(\frac{\rho_c N D_r^2}{\mu_c}\right)^{-0.155} \quad (9)$$

as well as the equation of the above-mentioned author [12] valid if the hold-up of dispersed phase Z approaches zero

$$\frac{d_{43} N^2 D_r^2 \rho_c}{\exp[0.0887 \Delta D]} = 45.3 \left(\frac{h_m}{D_c}\right)^{0.46} \quad (10)$$

where

$$\Delta D = \frac{D_c - D_r}{2}$$

Experimental

The experimental device consisted of a laboratory extraction column, lower and upper storage reservoirs for both phases, instruments and equipments serving for adjusting and controlling the flows, phase temperature, number of revolutions and maintaining the interface in column at a required height. The proper column was composed of a 1 m glass tube with 65 mm internal diameter, a system of the stator rings with 44 mm internal diameter the mutual distances of which were secured by spacing collars of 4 mm diameter.

An axis of 14 mm diameter driven by an electric motor with variable number of revolutions was situated in the centre of column. The discs of 30 mm diameter were so fixed to the axis that each of them lay between two vicinal stators constituting one stirring stage. The stators and discs were of 1 mm width. The whole working part of column was 60 mm long and consisted of 40 stages. The interface was maintained close over the last stator ring. The inlet tubes of phases were near the working part and the outlet tubes were built in the upper and lower head of column (Fig. 1).

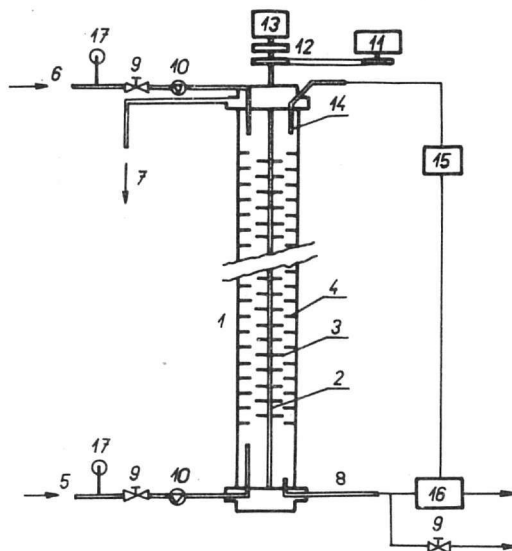


Fig. 1. Diagram of the device.

1. Glass tube; 2. axis; 3. rotor disc; 4. stator ring; 5., 7. inlet and outlet of toluene; 6., 8. inlet and outlet of water; 9. regulating valve; 10. rotameter; 11. electric motor; 12. tachometer dynamo; 13. revolution indicator; 14. electrode of the regulator of the height of interface; 15. relay; 16. solenoid valve; 17. thermometer.

Water was used as continuous phase while toluene represented the dispersed phase. Acetone was the substance proceeding in the direction $d \rightarrow c$. The dispersion of toluene in the column and the transfer of substance were promoted by intense mechanical stirring with rotating discs.

The size of drops was determined photographically with an Exacta apparatus equipped with an extension tube (material Ilford 26 DIN, f — number (1:16)—(1:22), back and side lightening 2×1000 W, exposure time $1/1000$ s). Before photographing the working part of column was set in a vessel of organic glass which had the form of right parallelepiped. This vessel was filled with water in order to compensate the wall curvature of column during photographing. The water temperature was equal to the mean temperature of both phases, *i.e.* 19°C . The photographic camera was mounted on a camera stand which could slide along the axis of column and its distance from the column allowed to photograph every three neighbouring stages. In each experiment the dispersion was photographed at five different

Table 1
Experimental conditions and experimental values of the parameters
of drop size distribution

Experiment	N min^{-1}	$U_d \cdot 10^3$ m s^{-1}	$U_c \cdot 10^3$ m s^{-1}	Z	\bar{a} mm	d_m mm	d_{mF} mm	β
1	622	1.67	3.03	0.095	6.18	5.53	5.56	0.332
2	674	1.73	3.03	0.114	5.54	4.68	5.01	0.366
3	725	1.70	3.03	0.129	5.09	4.33	4.90	0.360
4	778	1.69	3.03	0.168	4.63	3.86	4.40	0.358
5	844	1.67	3.03	0.232	4.05	3.02	3.80	0.660
6	622	1.88	2.72	0.098	6.27	5.80	5.56	0.333
7	674	1.87	2.72	0.104	6.17	5.61	5.52	0.350
8	725	1.85	2.72	0.138	5.32	4.37	5.01	0.385
9	778	1.84	2.72	0.171	3.91	4.12	4.95	0.286
10	844	1.79	2.72	0.219	3.43	4.02	4.97	0.347
11	926	1.86	2.72	0.230	3.69	2.98	3.85	0.466
12	622	2.16	2.39	0.116	5.84	5.48	5.56	0.344
13	674	2.08	2.39	0.125	5.35	5.40	5.36	0.274
14	725	2.08	2.39	0.161	4.70	4.49	5.01	0.332
15	778	2.13	2.39	0.172	3.89	4.55	4.90	0.312
16	844	2.11	2.39	0.216	2.98	4.11	4.95	0.263
17	926	2.09	2.39	0.250	2.92	3.68	5.07	0.335
18	622	2.29	1.94	0.128	5.75	5.62	5.50	0.285
19	674	2.31	1.94	0.143	4.89	5.23	5.50	0.242
20	725	2.28	1.94	0.163	4.46	5.37	5.52	0.212
21	778	2.26	1.94	0.186	4.20	4.81	4.97	0.296
22	844	2.23	1.94	0.225	3.13	4.41	3.95	0.700
23	926	2.19	1.94	0.260	—	—	—	—
24	622	2.45	1.79	0.117	6.30	5.62	5.48	0.228
25	674	2.44	1.79	0.154	4.97	5.45	5.55	0.245
26	725	2.41	1.79	0.171	4.75	5.12	5.57	0.256
27	778	2.40	1.79	0.188	4.17	5.00	5.04	0.210

places of column and the degree of drop enlargement was determined from the ratio of the diameter of real and photographed spacing collar and varied from 3.55 to 3.68. Owing to the centrifugal force due to the rotating discs the drops moved at the wall of column. Therefore it could be expected that each picture corresponded to a representative sample of dispersion.

The photographs were used for the determination of the interval distribution of drop sizes with respect to their number. This measurement was carried out with a jaw gauge and electric recorder which enabled us to find out the number in particular size intervals. The number of drops thus processed for individual experiments varied in the range 5000—9000. The working conditions chosen for individual experiments were under critical values in order to prevent the congestion of the column (Table 1). The input concentration of acetone in water was equal to zero while it was equal to 107 kg m^{-3} in toluene for all experiments. The density of toluene was 868 kg m^{-3} and the viscosity of toluene and water was $6 \times 10^{-4} \text{ Pa s}$ and 10^{-3} Pa s , respectively.

Results and discussion

From the data obtained by evaluating the photographs of dispersion in five places of the column the values of d_{32} and d_{43} given in Table 2 were calculated by

Table 2

Comparison of the measured and calculated mean diameters of drops

Experiment	d_{32} measured mm	d_{32} according to (17) mm	d_{32} according to (14) mm	d_{43} measured mm	\bar{a}/d_m	Correlation coefficient r
1	2.88	2.91	5.53	3.27	1.117	0.9877
2	2.54	2.54	5.30	2.88	1.182	0.9874
3	2.32	2.34	5.40	2.66	1.172	0.9878
4	2.04	2.11	4.78	2.34	1.200	0.9874
5	1.64	1.73	7.70	1.94	1.340	0.9938
6	3.00	3.01	5.55	3.39	1.081	0.9838
7	2.91	2.94	5.80	3.14	1.100	0.9833
8	2.36	2.40	5.77	2.68	1.220	0.9889
9	1.98	2.00	4.24	2.32	0.948	0.9882
10	1.81	1.85	5.17	2.28	0.852	0.9904
11	1.60	1.65	5.38	1.78	1.238	0.9948
12	2.83	2.83	5.73	3.24	1.064	0.9872
13	2.71	2.69	4.40	3.14	0.991	0.9844
14	2.28	2.30	4.98	2.66	1.048	0.9877
15	2.03	2.06	4.58	2.49	0.876	0.9987
16	1.79	1.73	3.90	2.32	0.725	0.9930
17	1.69	1.63	5.10	2.36	0.793	0.9919
18	2.97	2.84	4.71	3.54	1.022	0.9796
19	2.63	2.53	4.00	3.15	0.935	0.9834
20	2.45	2.44	3.50	2.33	0.831	0.9818
21	2.19	2.24	4.41	2.58	0.871	0.9910
22	1.88	1.83	8.30	2.14	0.709	0.9973
23	—	—	—	—	—	—
24	3.10	2.97	3.75	3.42	1.120	0.9786
25	2.57	2.60	4.00	3.07	0.911	0.9831
26	2.45	2.46	4.27	2.85	0.928	0.9833
27	2.24	2.27	3.20	2.67	0.835	0.9800

means of eqn (2). In order to verify the validity of eqn (5), this equation was transformed into the following form by means of eqns (2) and (3)

$$f\left(\frac{d}{d_m}\right) = \frac{1}{\beta} \exp\left[-\frac{d}{\beta d_m}\right] \quad (11)$$

The value of parameter β was sought on the basis of the condition of minimum of the function

$$Q = \sum_{i=1}^{10} (Y_{i,\text{meas}} - Y_{i,\text{calc}})^2 \quad (12)$$

where $Y_{i,\text{meas}}$ was the measured and $Y_{i,\text{calc}}$ the calculated value of the relative frequency of drops with the diameter d_i which was a class character of the interval i corresponding to the experimental size distribution. Because of this interval character it holds

$$\begin{aligned} Y_{i,\text{calc}} &= \int_{d_i - (\gamma/2)}^{d_i + (\gamma/2)} \frac{1}{\beta} \exp\left[-\frac{d}{\beta d_m}\right] dd = \\ &= d_m \left[\exp\left(-\frac{d_i - \frac{\gamma}{2}}{\beta d_m}\right) - \exp\left(-\frac{d_i + \frac{\gamma}{2}}{\beta d_m}\right) \right] \end{aligned} \quad (13)$$

where γ is the width of interval. The symbol d_m stands for the value of the experimental maximum diameter of drop. By using eqns (2) and (11) we may obtain the following expression for this distribution

$$d_{pq} = (\beta d_m)^{p-q} \frac{p!}{q!} \quad (14)$$

Eqn (6) may be transformed by means of eqn (3) into the form

$$v(d) = \frac{B}{d^2 d_{30}} \exp\left[\frac{-\bar{a}}{d}\right] = \frac{\bar{a}}{d^2} \exp\left[\frac{\bar{a}}{d_m} - \frac{\bar{a}}{d}\right] \quad (15)$$

because it holds according to eqns (2) and (6)

$$d_{30} = \frac{B}{\bar{a}} \exp\left[-\frac{\bar{a}}{d_m}\right] \quad (16)$$

In this case it follows for the mean diameter d_{32}

$$d_{32} = \frac{\bar{a}}{1 + \frac{\bar{a}}{d_m}} \quad (17)$$

The relationship between the distribution and frequency function is expressed by the following equation

$$\int_0^{d_i + (\gamma/2)} v(d) dd = V\left(d_i + \frac{\gamma}{2}\right) \quad (18)$$

This integral is to be solved by means of eqn (15) and it results

$$V\left(d_i + \frac{\gamma}{2}\right) = \exp\left[\frac{\bar{a}}{d_m} - \frac{\bar{a}}{d_i + \frac{\gamma}{2}}\right] \quad (19)$$

or

$$\ln V\left(d_i + \frac{\gamma}{2}\right) = \frac{\bar{a}}{d_m} - \frac{\bar{a}}{d_i + \frac{\gamma}{2}} \quad (20)$$

According to this expression the dependence of $\ln V$ on $1/(d_i + \gamma/2)$ is a linear function with the slope $-\bar{a}$, the section on ordinate y being \bar{a}/d_m . Therefore the parameters of distribution \bar{a} and d_m can be determined graphically while $V(d_i + \gamma/2)$ is to be determined experimentally

$$V\left(d_i + \frac{\gamma}{2}\right) = \frac{\sum_{d_{\min}}^{d_i} n_i d_i^3}{\sum_{d_{\min}}^{d_{\max}} n_i d_i^3} \quad (21)$$

For illustration, the plot representing eqn (20) for experiment 15 quoted in Table 1 is given in Fig. 2. On the other hand, in Fig. 3 the form of both distributions tested is confronted with experimental values. The values of \bar{a} , d_m , and β found as well as the maximum drop diameters d_{mF} determined by means of

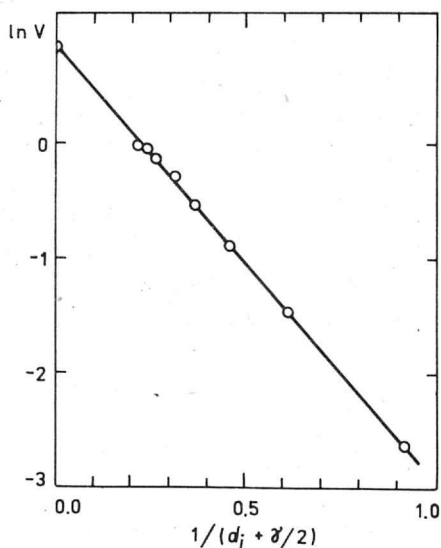


Fig. 2. Variation of $\ln V(d_i + \gamma/2)$ with $1/(d_i + \gamma/2)$ according to eqn (20) for experiment 15.

$$\bar{a} = 3.89 \times 10^{-3} \text{ m}; \quad d_m = 4.35 \times 10^{-3} \text{ m}; \quad \bar{a}/d_m = 0.895.$$

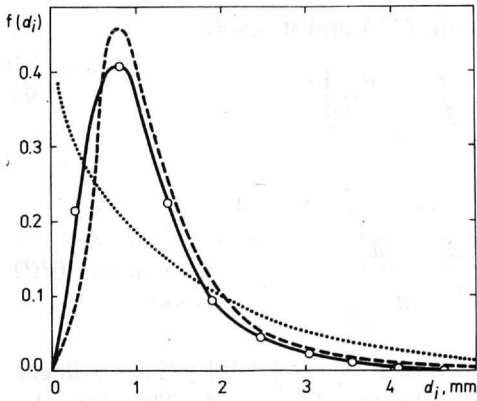


Fig. 3. Experimental distribution of the drop sizes and the distribution calculated according to eqns (5) and (6) for experiment 15.

○ Measured; calculated according to (5);
----- calculated according to (6).

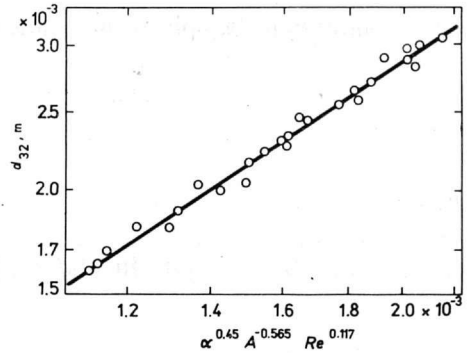


Fig. 4. The course of relationship (31) and the measured values of d_{32} .

photographs are presented in Table 1 while the mean values of d_{32} calculated according to eqns (14) and (17) are quoted in Table 2. The correlation coefficients r calculated for individual linear relationships of type (20) are also given.

It ensues from the confrontation of experimental values with eqn (11) (Fig. 3) that expression (5) for the distribution of drop sizes is of empirical character and for this reason, its modification into the form $f(d)$ by means of eqn (3) does not conform to physical reality. The curve shows no maximum and for $d_i \rightarrow 0$ we obtain $f(d_i) = 1/\beta$. By reason of this fact, we are able to explain the great differences between the measured and according to (14) calculated values of d_{32} . Since the aim of this investigation was merely to find out a convenient distribution of drop sizes and not a detailed study and confrontation of several relationships proposed, the equation put forward by Přerovská (5) was not tested.

It ensues from Fig. 3 and Table 2 that the distribution of drop sizes according to Schwarz is in good agreement with the experimental values obtained. The agreement between the measured and calculated values of d_{32} is very good. The values of \bar{a} and d_m decrease with increasing number of revolutions and in contrast to the conclusions of Sprow [13] their ratio \bar{a}/d_m must not be considered constant. The comparison of the measured and calculated values of d_m shows a good agreement for lower values of N and U_d/U_c but the differences increase with the values of N .

The mathematical form of the distribution according to Schwarz, however, shows a certain drawback consisting in that it does not allow an analytical calculation of the mean diameters d_{pq} for $p, q > 3$ in the sense of definition eqn (2) because an

integral exponential function the value of which can be calculated only numerically appears in this case. The distribution according to Přerovská does not have such a limitation.

As a theoretical solution of the problem concerning the relationship between the distribution parameters of drop sizes and the quantities characterizing the experimental conditions has not been elaborated yet, we are obliged to find out the correlation relations for \bar{a} , d_m , and d_{32} by the use of dimensional analysis.

For the two-phase flow in an RD column the set of the quantities involved may be written in the form

$$\{h_c, h_m, D_r, D_s, D_c, U_c/(1-Z), U_d/Z, N, \rho_c, \Delta\rho, \mu_c, \sigma, \omega\} \quad (22)$$

where ω is the quantity the variation of which should be determined. The expressions $U_c/(1-Z)$ and U_d stand for the velocities of phases referred to the real free cross-section of column. From these quantities we obtain the criterial function

$$f\left(\alpha, n, A, \frac{D_r}{h_c}, \frac{D_s}{h_c}, \frac{D_c}{h_c}, \frac{\Delta\rho}{\rho_c}, Re, \frac{\rho_c h_c \sigma}{\mu_c^2}, \bar{\omega}\right) \quad (23)$$

where

$$\alpha = \frac{U_d(1-Z)}{U_c Z}, \quad Re = \frac{\rho_c h_c U_c}{\mu_c(1-Z)}, \quad A = \frac{D_r N(1-Z)}{U_c} \quad (24)$$

and $\bar{\omega}$ is a dimensionless quantity ω . As neither the physical properties of the two-phase system nor the internal geometrical arrangement of the column changed, eqn (23) may be simplified into the form

$$f(\alpha, A, Re, \bar{\omega}) = 0 \quad (25)$$

while the expected form of the functional dependence is

$$\bar{\omega} = k_0 \alpha^{k_1} A^{k_2} Re^{k_3} \quad (26)$$

The numerical values of the constants k_0 – k_3 may be found after taking logarithm of this expression by the method of least squares. The mean relative error δ

$$\delta = \frac{\sum_{i=1}^n \frac{|y_{i,calc} - y_{i,meas}|}{y_{i,meas}}}{n} \quad (27)$$

and the maximum relative error δ_m

$$\delta_m = \left(\frac{|y_{calc} - y_{meas}|}{y_{meas}} \right)_{\max} \quad (28)$$

may be used as a criterion of accuracy.

The correlation relationships serving for determining the parameters of the distribution of sizes and mean diameter d_{32} ascertained on the basis of eqn (26) by means of experimental values assume the following form

$$\frac{\bar{a}}{D_r} = 1.37 \times 10^5 \alpha^{0.212} A^{-1.44} Re^{-0.94} \quad (29)$$

$$\delta = 0.0620, \delta_m = 0.2181.$$

$$\frac{d_m}{D_r} = 6.8 \times 10^{-3} \alpha^{0.514} Re^{0.31} \quad (30)$$

$$\delta = 0.0474, \delta_m = 0.1655.$$

$$\frac{d_{32}}{D_r} = 1.43 \alpha^{0.45} A^{-0.565} Re^{-0.117} \quad (31)$$

$$\delta = 0.0195, \delta_m = 0.0591.$$

For illustration, relationship (31) is graphically compared with the experimental values (Fig. 4).

The values of mean diameters found experimentally were confronted with eqn (8) modified for the experimental conditions

$$d_{32} = 1.9 \times 10^{-2} N^{-0.972} \quad (32)$$

and with eqn (10) modified into the form

$$d_{43} = 0.75 N^{-2} \quad (33)$$

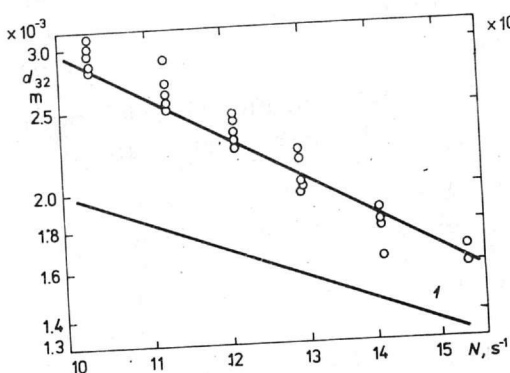


Fig. 5. Experimental values of d_{32} and relationship (32) (curve 1).

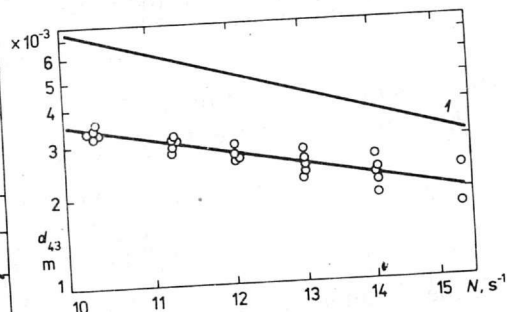


Fig. 6. Experimental values of d_{43} and relationship (33) (curve 1).

Figs. 5 and 6 show these confrontations for all experiments. The measured values are in best agreement with the following relations

$$d_{32} = 0.111 N^{-1.55} \quad (34)$$

and

$$d_{43} = 6.72 \times 10^{-2} N^{-1.29} \quad (35)$$

As obvious from the above figures, the examined correlation relationships are not in sufficient agreement with the values measured while the differences appear not only in the values of the constants of individual relations but also in the value of exponents. As for the first relation, this disagreement may be explained by that it does not involve the velocities of both phases in the flow apparatus and, moreover, the experimental data were obtained for the conditions of substance transfer when the effect of different surface phenomena on the size of drop could not be excluded (Marangoni effect, etc.). This argument can be also used for a partial explanation of the difference between the experimental values and the values calculated by means of eqn (33). Besides, it has to be taken into consideration that the experimental conditions were not quite consistent with the conditions necessary for the validity of the above equation, *i.e.* the state when $Z \rightarrow 0$. From this point of view this difference (irrespective of the effect of substance transfer) may be used as an argument to state that the splitting of drops prevailed over aggregation in the laboratory extraction column used if the reference state was fixed by the validity of eqn (33).

The validity of relations (29—33) is limited by the conditions under which the experiments were performed, *i.e.* it is restricted to the internal geometrical arrangement of column used and the system water—acetone—toluene. For a generalization of results in a broader range of working conditions which necessitates to study the character of two-phase flow in column [15] it will be necessary to pay attention to the problem of the determination of the distribution parameters.

Symbols

- \bar{a} parameter of the drop size distribution (6)
- A quantity defined by eqn (24)
- B function defined by relation (7)
- d diameter of drop
- d_i diameter of the i -th drop
- d_{pq} mean diameter defined by relation (2)
- d_m maximum diameter of drop

D_r	rotor diameter
D_s	stator diameter
D_c	column diameter
E'	power input for a unit of stirred substance
$f(d)$	frequency function of the drop size distribution according to number
$F(d)$	distribution function of the drop size distribution according to number
h_m	height of stirring stage
h_c	length of column
n	number of stirring stages
n_i	number of drops in the i -th interval
N	number of rotor revolutions per time unit
P_d	power input per one stirring stage
Re	Reynolds number defined by relation (24)
U_c	velocity of continuous phase
U_d	velocity of dispersed phase
$v(d)$	frequency function of the drop size distribution according to volume
$V(d)$	distribution function of the drop size distribution according to volume
V	volume of the working part of apparatus
V_d	volume of dispersed phase
Z	hold-up of dispersed phase
α	quantity defined by eqn (24)
β	parameter of the drop size distribution (5)
γ	width of interval
δ	relative error defined by relation (27)
δ_m	maximum relative error defined by relation (28)
μ_c	viscosity of continuous phase
ρ_c	density of continuous phase
$\Delta\rho$	difference between the densities of both phases
σ	interfacial tension
ω	quantity in the sense of relation (22)

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Translated by R. Domanský